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Title Nutritional Implications of High-Tech Foods, Should combat rations be high fat or low fat?

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Intended for publication in Proceedings of the fall 1988 meeting of the Research and Development Associates.

Intended for presentation before R&DA Fall General Membership Meetings

Location Natick, MA, USNRDEC Date 6 Oct 1988

2. Budget Project No. 3M263002D819 Cost Code 9410089102071

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NUTRITIONAL IMPLICATIONS OF HIGH-TECH FOODS

Should combat rations be high fat or low fat?

Reed W. Hoyt, Ph.D.

A presentation to the Research and Development Associates Fall 1988 Meeting, USNRDEC, Natick, MA, 6 Oct 1988.

INTRODUCTION

Modern combat scenarios suggest soldiers must be prepared for short term high intensity conflict on fluid battlefields where there are no established lines of supply. In addition to water, these soldiers will need compact, light weight, shelf-stable rations that are readily consumed in order to maintain optimal physical and mental performance. There has been a long history of concentrated food development for the military directed towards meeting these requirements (Calloway, 1986). One of the challenges before us today is to enhance the utility and efficacy of the rations provided to our armed forces by providing appropriate amounts of macronutrients (Askew, 1986). An active research program with close cooperation among ration developers and nutritional physiologists is essential to meeting this challenge.

After a short discussion of fuel storage and utilization, two collaborative research projects will be presented. In these studies, metabolic and performance testing were used to improve our understanding of the respective roles of dietary fat and body lipid stores in meeting the fuel requirements of soldiers and Marines.

FAT AND CARBOHYDRATE STORAGE AND UTILIZATION

Dietary energy intake in excess of energy expenditure normally leads to increased body fat stores. Neutral fats can be stored in a dehydrated state. They have a high free energy content per unit weight, releasing 9 kcal/g on complete combustion. In man, the total energy content of body fat stores can exceed 10,000 kcal. In contrast, the body's total carbohydrate storage capacity is limited to one to two percent that of fat (approximately 1500-2500 kcal). This is due in part to the water required for storage, and the lower energy

density (4 kcal/g) of carbohydrates. However, carbohydrates are readily oxidized, support twice the rate of power production possible when fat alone is combusted, and are needed for peak physical performance (Costill, 1988; Sahlin, 1986)(Tables 1,2).

ENERGY BALANCE DURING A HIGH-ALTITUDE COLD-WEATHER FIELD TRAINING EXERCISE - A COMPARISON OF THREE RATION SYSTEMS

In January 1988, the U.S. Army Research Institute of Environmental Medicine (USARIEM), carried out a research study at the Marine Corps Mountain Warfare Training Center, Bridgeport, California. This study was carried out in collaboration with the Food and Engineering Directorate of the Natick Research and Development and Engineering Center (NRDEC) and the U.S. Marine Corps.

The main objectives were to measure the energy expenditure of 28 Marines from the Mountain Leader Training Course who were engaged in strenuous winter training at altitude, and to evaluate the suitability of three different field ration systems: the Ration, Cold Weather (RCW), the Ration, Light Weight (RLW), and the Meal, Ready-to-Eat (MRE VIII), as the sole sources of food for 12 consecutive days. There was a minimum of interference by scientists with the training activities of the Marine.

The recently validated doubly labeled water technique for measuring energy expenditure in humans (Jequier, et al. 1987) and standard nutritional field techniques, such as food and fluid logs, were used in this study. The double labeled water technique is particularly well suited to use in the field. Briefly, the subject drinks water containing heavy hydrogen and heavy oxygen. Both isotopes are non-radioactive and occur naturally. The heavy hydrogen equilibrates with the body water pool, while the heavy oxygen equilibrates with both the water and the carbon dioxide pools. The heavy hydrogen is lost from the body via water, while the heavy oxygen is lost via water and carbon dioxide. Therefore, the amount of carbon dioxide produced can be calculated by subtracting the rate of loss of heavy hydrogen from the rate of loss of heavy oxygen. This can then be converted to energy expenditure using direct measurements or estimates of the Respiratory Exchange Ratio or RER. The RER

is the ratio of carbon dioxide production to oxygen consumption. Preliminary results indicate that daily energy expenditure while in the field averaged approximately 5300 $\pm$ 265(SE) kcal/man. The calories consumed on the three rations averaged 2892 $\pm$ 103 kcal/man/day for the RCW, 3205 $\pm$ 137 kcal/man/day for the RLW, and 3205 $\pm$ 101 kcal/man/day for the MRE (Morgan et al., 1988). These data confirm the high energy demands of this intensive winter mountain warfare training program.

EFFECT OF LIPID AND TOTAL CALORIE CONTENT OF A RATION ON METABOLISM AND ENDURANCE EXERCISE PERFORMANCE

USARIEM, again in close collaboration with the NRDEC, conducted a laboratory study of the effects of lipid and total calorie content on soldier metabolism and endurance exercise capacity. The main objective of the experiment was to assess whether the addition of fat to a diet containing a minimal amount of carbohydrate and protein had any influence on metabolism or endurance exercise performance. A secondary objective was to assess whether there was evidence of a carbohydrate deficiency when 300 g carbohydrate /man/day was fed to individuals expending 4000 kcal/day.

In this crossover study eight soldiers alternately fed either a 2300 kcal or a 3300 kcal diet while they participated in a four-day program of standardized exercise. The two diets had similar amounts of carbohydrates and protein but differed widely in lipid and total fat calorie content (Table 3).

During the four-day exercise program, the soldiers spent three hours per day engaged in intermittent exercise, rotating among four different exercise machines: a treadmill, rowing ergometer, cross-country ski machine, and bicycle ergometer. Total energy expenditure was approximately 4000 kcal/day. On day five, the subjects donned a 15 kg backpack and engaged in a prolonged treadmill test of endurance exercise capacity.

Measurements of nitrogen balance, fecal fat, blood hormone and fuel levels, fuel oxidized, oxygen consumed, carbon dioxide produced, and endurance exercise capacity were made. The results show that differences in dietary fat intake had

no significant influence on any of these measures. The RER at rest and during exercise, as well as changes in blood metabolite levels, indicated a transition from a carbohydrate- to a fat-predominant metabolism with both diets (Figs. 1A, 1B). Assuming a minimal contribution of proteins, the RER will be 1.0 when carbohydrates alone are being oxidized. When fat alone is being oxidized the RER will be 0.7.

Although the diets differed in calorie content due to differences in total fat content, the subjects evidently met the additional metabolic requirement for fat by drawing on body fat stores. The net result was that the RER, i.e. the metabolic mixture being oxidized, and the other physiological parameters that were measured, did not differ significantly between diets. This suggests that in the short term, metabolic requirements for lipid fuel can be readily met by mobilizing body fat stores.

DISCUSSION

During field exercises, energy expenditure frequently exceeds dietary energy intake resulting in a loss of body mass. This is not entirely unexpected situation in light of the many constraints on nutrient intake. The amount and palatability of the rations, as well as the time available to the soldier to prepare and eat them, are often limited. However, when highly palatable rations are provided and soldiers are provided adequate time to eat energy, energy intakes will match expenditure and body weight will be maintained even during a 8-day sustained artillery operation (Rose and Carlson, 1986).

If operational rations are to be consumed for prolonged periods of time, additional dietary fat is one way to try and achieve caloric homeostasis and minimize the drain on body fat stores. From a physiological perspective, one of the most important and widespread uses of energy-dense lipids is for endogenous fuel storage (Symposium on Lipids in Animal Life Histories, 1976). It is self-evident that an individual that has energy stored for later use when energy intake does not meet energy expenditure will have a competitive advantage. When field operations are prolonged beyond two to four

weeks, it becomes increasingly important to minimize the drain on body fat stores to avoid soldiers entering periods of energy imbalance with marginal body energy reserves.

However, during field exercises less than two weeks in duration there appears to be no advantage to a high dietary fat intake since body fat stores are normally readily available to buffer any shortfall in dietary energy intake. The modern combat soldier engaged in physically demanding field operations of less than 10-14 days duration will likely have high rates of energy expenditure and little time to consume a restricted mass and volume of rations. These soldiers are not in danger of starvation, but in danger of carbohydrate depletion and an associated decrease in physical and possibly mental performance (Military Nutrition Research Annual Report on Calorie Dense Rations, 1988). In this situation, micronutrients and the amounts of carbohydrate and protein are probably more important determinants of soldier well-being than the amount of dietary fat.

In conclusion, a reduction in the fat and total fat calorie content of combat rations appears to be an effective way of either reducing the mass and volume of the ration or increasing the room available for carbohydrates. The transient reliance on body fat when food intake is limited can result in adequate nutrition, particularly when the carbohydrate content of the rations is maximized so that it complements the primarily lipid fuel being provided from body energy stores.

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Table 1. Fuel Storage in Man

Aerobic metabolism	Available Energy (mol ATP)	Work Time at 70% VO_2max (min)
Carbohydrates ---> CO_2 + H_2O	130	171
Free Fatty Acids ---> CO_2 + H_2O	8000	10600

The available energy was calculated assuming a 20 kg muscle with a glycogen content of 150 mmol/kg wet weight, a 500 mmol liver glycogen store, and 15 kg body fat store. Work time was calculated from a VO_2max of 4 l/min, with the hypothetical assumption that either carbohydrates or free fatty acids were the sole source of energy. (Adapted from Sahlin, 1986.)

Table 2. Power and Acceleration Time of Fat and Carbohydrate Energy Sources

Aerobic metabolism	Max Power	Time to Reach Max Power
Carbohydrates ---> $C0_2 + H_20$	2.7	3 min
Free Fatty Acids ---> $C0_2 + H_20$	1.4	30 min

Maximum aerobic power, expressed as mmol ATP/kg dry muscle/sec, was calculated assuming that 72% of a $V0_2$max of 4 l/min was utilized by a working muscle mass of 20 kg (4.7 kg dry mass). The maximal power of free fatty acid oxidation was assumed to correspond to the apparent upper limit of 50% of $V0_2$max (Davies & Thompson, 1979). The relatively slow mobilization of free fatty acids from body fat stores prolongs the time needed to acheive maximum power when fats are combusted. (Adapted from Sahlin, 1986.)

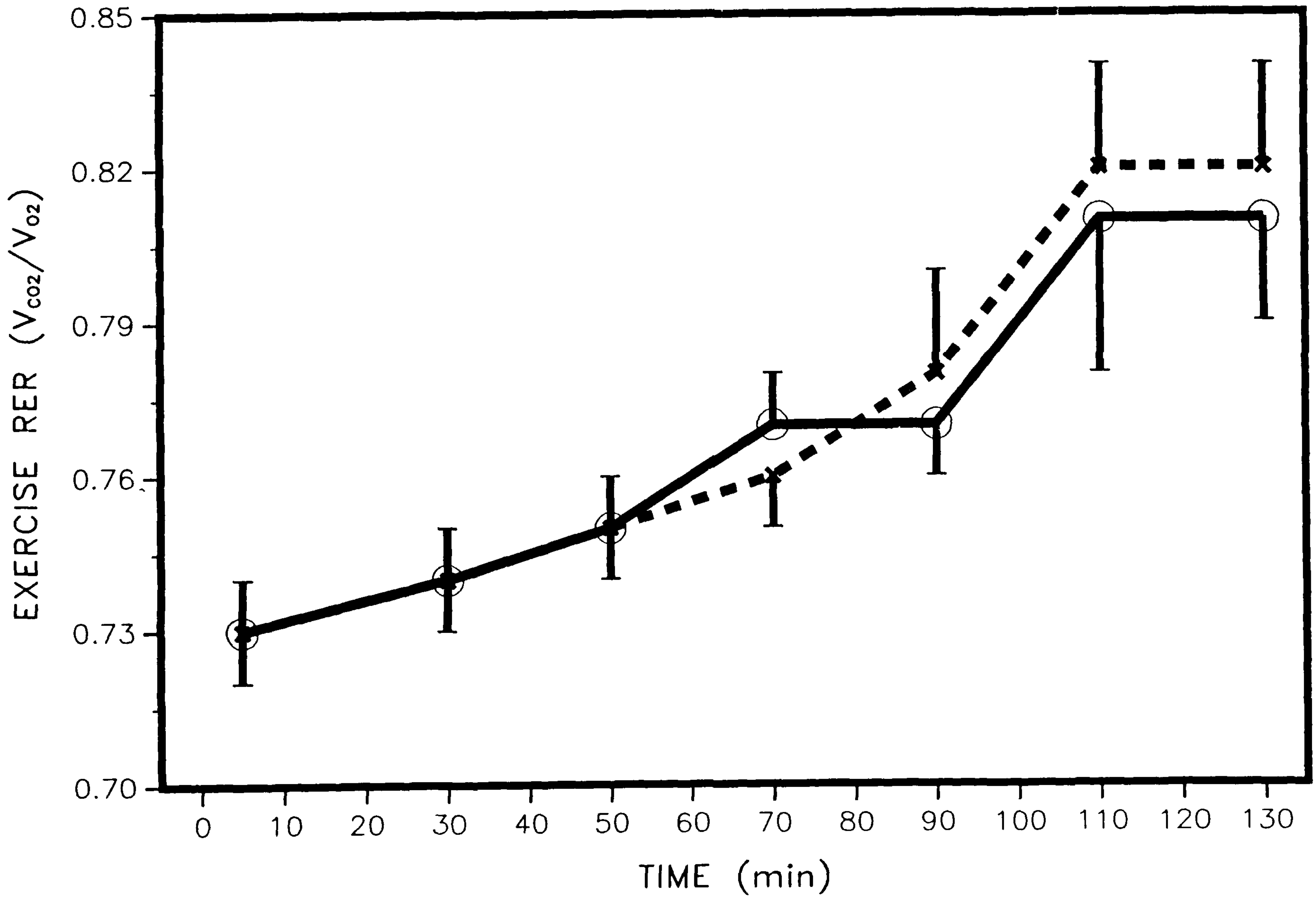
Table 3. Test Ration Composition

	Low Fat Diet 2300 kcal	High Fat Diet 3300 kcal
Protein (g)	68	68
Carbohydrate (g)	282	287
Fat (g)	100	209
Energy (kcal)	2301	3305
% kcal as fat	39	57
Weight (g)	450	561

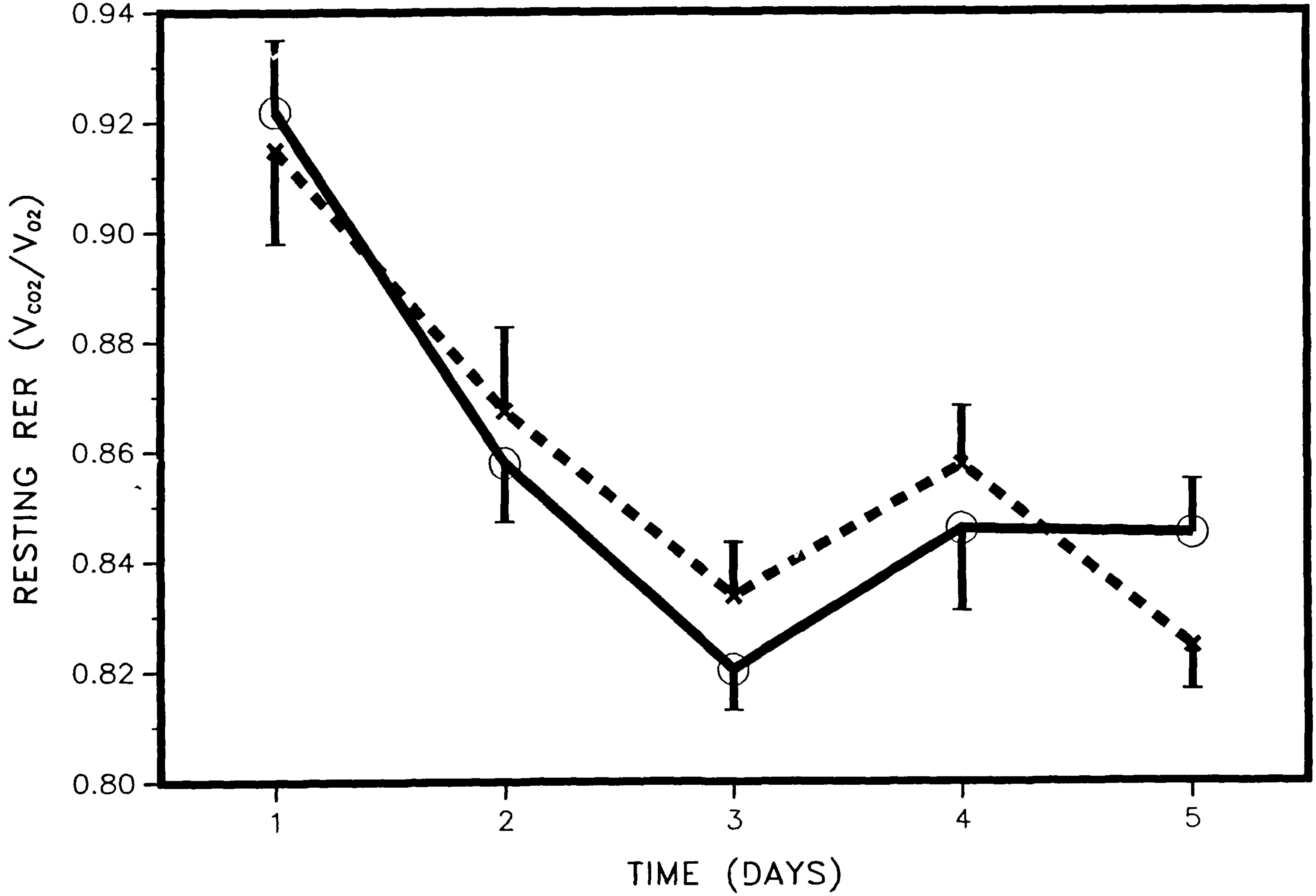
Figure Legends

1A. Respiratory exchange ratio (RER) during continuous progressive treadmill exercise to exhaustion. RER normally reaches or exceeds 1.0 in carbohydrate replete individuals. (X's indicate the Low Fat Diet; Open circles indicate the High Fat Diet.)

1B. Respiratory exchange ratio (RER) measured each morning in supine awake subjects. (X's indicate the Low Fat Diet; Open circles indicate the High Fat Diet.)



0.85
0.82
0.79
0.76
0.73
0.70
EXERCISE RER (V_{CO2}/V_{O2})
0
10
20
30
40
50
60
70
80
90
100
110
120
130
TIME (min)


0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
RESTING RER (V_{CO2}/V_{O2})
1
2
3
4
5
TIME (DAYS)